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COMPARISON OF AERODYNAMIC COEFFICIENTS OBTAINED FROM THEORETICAL CALCULATIONS WIND TUNNEL TESTS AND FLIGHT TESTS DATA REDUCTION FOR THE ALPHA JET AIRCRAFT

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COMPARISON OF AERODYNAMIC COEFFICIENTS RESULTING FROM THEORETICAL CALCULATIONS, WINDTUNNEL EXPERIMENTS AND EXPERIMENTS CARRIED OUT DURING FLIGHT ON AN ALPHA JET /19-1*

by

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Summary

After presenting the methods used to determine the aerodynamic coefficients by: calculations, windtunnel experiments and later on experiments carried out in flight on various prototypes of the Alpha-Jet, a comparison of the obtained results is made which shows good correlation in general between the expectations and the results in flight and which is commented upon.

Introduction

Beyond getting to know the craft during the experiments, the comparison of aerodynamic coefficients calculated, or derived from windtunnel experiments, with the results obtained in flight presents various sources of interest for engineers engaged in defining the aerodynamics of airplanes. The most important of them is certainly to be able to answer the question:

"Within what limits and to what accuracy can results from calculations and from windtunnel experiments be considered as valuable?"

The answer to that question is of primary importance in the case where a prototype, built according to an entirely new aerodynamic formula, is created.

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*Numbers in the margin indicate pagination in the foreign text.

The comparative study of expectations and results obtained in flight is presented here starting from the experience acquired in the course of adjusting the Alpha-Jet and enriched by what has already been obtained from the study of numerous prototypes built by the Dassault-Breguet and Dornier Companies.

1. Expected Aerodynamic Coefficients

The forecast of aerodynamic coefficients was made several times through:

1) Use of the manuals
   USAF Stability and Control DATCOM and
   Royal Aeronautical Society DATA Sheet (England)
2) In parallel with those simplified results, two-dimensional and three-dimensional calculations relating particularly to the wings and the interaction between wing and fuselage.
3) Windtunnel models.
   a) Results gained from the manuals (references 1 to 5) DATCOM and DATA Sheet were used, together with various documents and reports from the files of the DORNIER and DASSAULT-BREGUET companies.
   b) Theoretical calculations in two and three dimensions (references 6 to 9).
      These calculations were used to find a reasonable compromise between the different exigencies. For example:

Performance	Maximum velocity (Cxo) Scope of maneuverability (Cx=f (Cz,M) Landing and takeoff velocities (Cz max) Boundaries of maneuverability (max usable Cz f(M)
Flight qualities	Rolling velocities (Cl δL) Correct demonstration spin
Restrictions to Geometric Definition	Developable surface Wing thickened at the root Wings without variable geometry of the leading edge

Various methods of calculation were used during the development of the Alpha-Jet. Fig. 3 shows the limits for the validity of these calculations as a function of the Mach number.

1) Potential [energy] flow
Calculations of air flow can be made with good accuracy up to just a little beyond the critical Mach number as an aid in the method of singularities. The RAE method can provide good results with relatively short time spent in calculation.

2) Separated flow (Fig. 2)
These methods are used to identify the points of flow separation along the wingspan and to calculate the lift angles, including all the incidents of separation.

c) Windtunnel experiments /19-2
The difficulties encountered in completing this program, while observing the requirements of simplicity made for this airplane, (in particular the prohibition of variable geometry for the leading edges) were responsible for a large number of windtunnel experiments, which were at first carried out with different models.

	Definition	Utilization		Windtunnel
1	Low velocities Scale: 1/5	High lift operation Motorization Ground effect	Lateral coefficients at low speed Loads on elements	AVA Göttingen
2	Low velocities Scale: 1/5	Dynamic coefficients at low speed		ONERA S2 Chalais
3	High velocities Scale: 1/10	Longitudinal and lateral coefficients Efficiency of the control surfaces Influence of outside loads		NRL Amsterdam ONERA S2 Modane
4	Half-model Low velocities Scale: 2/5	High lift operation Definition of the leading edges		S5 CEAT Toulouse ONERA S1 Modane
5	Scale: 1/3	Model of air intake		DFVLR Brunswick Immenstaadt ONERA S1 Modane
6	Buffeting model			ONERA S2 Modane
7	Spin models			IMF Lille

d) corrections of windtunnel tests (references 10 to 13).

1) Corrections due to restraints of the walls:

These corrections vary with the windtunnel:

--For the low speed windtunnel of Göttingen: the corrections for interference with the free jet flow are negligible, only the corrections for the lift effect applied to the drag, the lift and the pitching moment, are used.

Corrections for ground effect are used in the same way.

--For the French low speed windtunnel a complete program of corrections, including interference and lift effects, is used (as suggested by the documents in the reference) in a general way for the entire subsonic domain. Fig. 4 presents important corrections applied to the results, obtained from windtunnel S5 of the CEAT in Toulouse for a half-model at 2/5 scale.

--For a transsonic windtunnel with ventilated walls: the corrections are only applied for the analysis of suspect or critical data.

Some correction factors for lift are calculated by the Dassault-Breguet Company for its own personal requirements.

2) Corrections due to the Reynolds number.

In agreement with the experiences acquired on other airplanes, the corrections were applied to the drag.

3) Corrections due to aeroelasticity.

The aeroelastic effects are very important and should be considered for nearly all the derivatives. The effects are calculated

by means of a method that substitutes an elastic model for the airplane structure and by obtaining a balance of aerodynamic forces with internal forces on the structure.

The importance of these effects is shown in Fig. 5 by comparing the wing lift distribution of an elastic and a rigid wing under the effect of aileron deflections. The torsions and flexures of the wings induce an additional lift distribution, which reduces the efficiency of the ailerons markedly.

Not only the flexibility of the wing was taken into consideration but also the elasticity of the horizontal and vertical parts of the tail assembly, as well as the flexure of the rear fuselage. The calculation of deformation was made by means of the finite element method.

e) Similarity

For the models for spins and buffeting where aerodynamic phenomena of weight, inertia, or rigidity, are represented simultaneously, similarity between model and airplane must obviously be kept in mind.

Other phenomena, such as simulations of the jet stream or the release of outside loads can be applied in this concept of similarity.

2. Flight Tests for Identification /19-3

Identification of aerodynamic coefficients from the start of flight is obtained after carrying out a program of special experiments defined by the choice of:

(1) Reference points in the flight domain
(2) Reference configurations
(3) Related factors allowing the separation of coefficients

a) Reference points in the flight domain

Reference flight points are chosen from the "Mach number, altitude, indicated speed" domain to provide an answer to the following absolute requirements:

(1) determination of the Mach effect

Loads are applied for various Mach numbers at a constant indicated velocity and under balanced flight conditions.

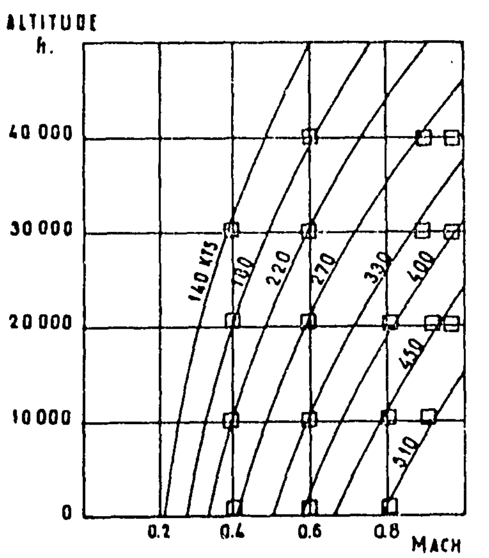
(2) determination of the effect of the angle of attack

Loads are applied for various load factors at a constant Mach number.

(3) determination of the dynamic pressure effect

Loads are applied under conditions of balanced flight at a constant Mach number and at the indicated variable velocity.

The choice of a flight test program, as easy to set up as it is to implement it, which includes the above absolute requirements leads to the establishment of the following fixed reference points shown in the diagram below and permits work at practically constant reference altitudes.



b) Reference configurations

Reference configurations are defined by:

--The position of mobile elements:

--wing flaps

--air brakes

--landing gears

--definition of the impact of significant outside loading.

To those reference configurations we must add the choice of the flight phase in which the tests are to be carried out for determination of:

--corrections for the influence of weight

--corrections for the influence of fuel, for instance: flying with a full wing or an empty wing.

Finally, though it is sufficient for most of the coefficients to run the tests at an average trim there are some coefficients for which it will be required to investigate the influence of the trim.

c) Typical operations and stresses

The flight phases employed for determination of the aerodynamic coefficients can be divided into three categories:

--very slow stabilizations and maneuvers (three minutes)

--slow maneuvers (20 to 40 seconds)

--fast maneuvers.

These categories can again be subdivided into the following organigrams below:

- Stabilization or very slow maneuvers
  - stabilized level flight
    - drag
    - calibration of angle of attack sensor
    - elevator deflection in balance
    - aerodynamic characteristics of the air intake stresses for $n_z=1$
  - slow sweep of the angle of attack
    - calibration of the angle of attack
    - drag
  - acceleration; deceleration; at constant altitude
    - drag
    - elevator deflections and in particular the influence of the engines on the steering mechanism
    - torque due to the airbrakes
  - low speeds
    - stall tests
    - lift due to angle of attack CZ (α)
    - elevator deflections
    - stresses on the flaps
  - landing; takeoff
    - drag
    - ground effect
  - boundaries of operation; excitation for buffeting
    - drag
- Slow Maneuvers
  - limits and boundaries of maneuvers; Deviation limits of the load factor
    - determination of relations
      - $CZ = f(\alpha)$
      - $CZ = f(\delta m)$
      - $CZ = f(Cm)$
    - moments and forces
      - wings
      - stabilizers
      - fuselage
      - pylon
      - outside loads
    - determination of influences
      - Cm due to airbrakes
      - CZ due to airbrakes
  - airbrake operations
    - moments and forces
      - airbrakes (saturation)
      - stabilizers
  - wing flap operations
    - moments and forces
      - wings
      - high lift devices
      - stabilizers
  - stabilized side slips
    - relations δL, β and δn β
    - forces and moments
      - direction (saturation)
      - vertical stabilizer
      - asymmetry of stabilizers
      - pylon
      - outside loads

- fast maneuvers
  - separate operations
    - force in the direction δn t or t
      - calibration of the sideslip sensor
      - transverse aerodynamic coefficients
      - forces and moments on the vertical stabilizer and rudder
    - banking force δL t or t
      - transverse aerodynamic coefficients and, in particular, roll control efficiency around the neutral axis
    - force on the elevator δm t or t
      - calibration of angle of attack sensor
      - longitudinal aerodynamic coefficients
    - stress relief after stabilized buffeting
      - forces and moments on the vertical stabilizer, the rudder and the tail unit when in asymmetry
  - coupled operations
    - horizontal spins
      - overall coefficients
      - forces and moments
        - wings
        - ailerons
        - pylons
        - outside loads
    - spins
      - comparison with windtunnel results

3. Identification From the Start of In-flight Recording /19-5

Following the recording of the airplane parameters in flight it is possible to define:

(1) a process of application and comparison with expected results
(2) corrections of the raw parameter data
(3) processing methods

(a) The process of utilization

Before starting the comparisons it will be necessary to dispose of:

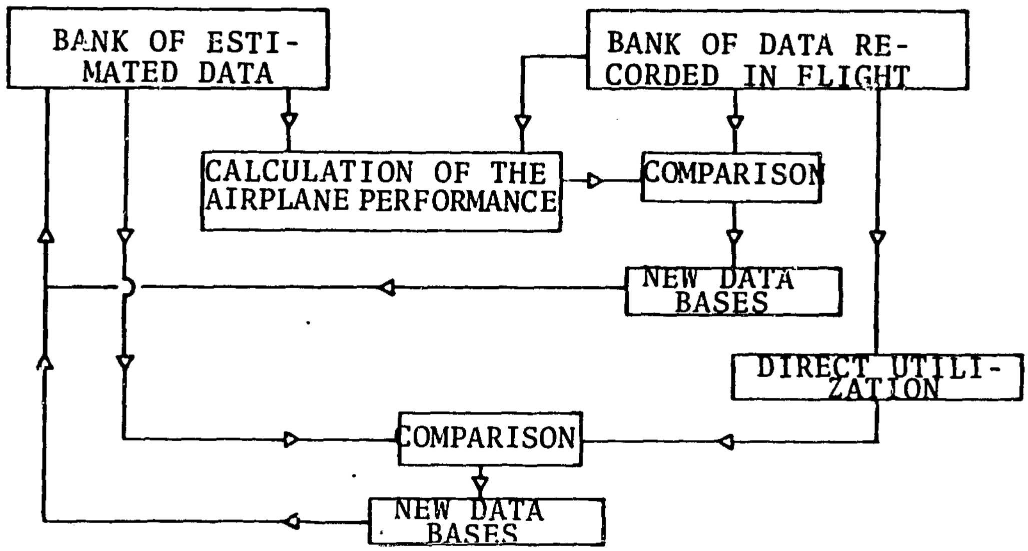
(1) a data bank of estimated data, rearranging:
--test results
--theoretical calculations
--bases related to weight and inertia
--estimated aerodistortion

(2) a bank of recorded data made during flights rearranging the various operations from the preceding chapter. That bank evidently augments its capital in the course of successive flights. The recordings are stored in elaborate form, i.e., after having undergone:
(1) calibrations
(2) corrections or necessary elementary calculations, particularly for recognition of flight conditions:
--corrections of anemometry
--calculation of centering starting with flowmeters
--elaboration of Mach number, of the corrected velocity, of the pressure altitude, starting with records of the static and dynamic pressures
--etc. . . .

Two procedures are then employed for obtaining the aerodynamic coefficients, according to the physical problem studied:

(1) a method of searching for variations between estimated data and flight data

(2) a method of direct investigation of aerodynamic coefficients:



Comparisons can be affected either:

--directly at the level of the estimated aerodynamic data bases, which allows generation of a bank of data obtained during flight.

--at the level of a reference model (for instance an airplane of calculated weight under conditions determined by its structural resistance). Only the estimated data bases valuable for the model will then be modifiable, but the model concept itself justifies the direction followed.

(b) Corrections and elaborations

In addition to the already mentioned corrections of anemometry, which allow determination of the exact flight conditions, various elaborations are carried out for obtaining the capability of determining the coefficients.

It is evidently not possible here to define all the procedures carried out but some are highly characteristic and can be given as example:

(1) elaboration of thrust

The engine serving for reference is the "test engine" tested at the altitude data bank of the engine test center for various conditions of Mach numbers and altitude.

The runs using the "test engine" data bank are used to readjust the performances shown by the manual and to define the relations of: thrust and internal parameters.

Each "flight" engine is then treated individually by comparison with the "test" engine in a power check. /19-6

Two procedures are then used:

*The consumption method:

Linking results dealing with:

--the "test engine"

--the engine as defined by the plans of the designer, with its characteristics presented by the output of a single duct and by zero air samples and power

--the power plant coefficients given by the design manual

together with individual tests of engines mounted on the airplane the following relations can be determined:

Thrusts and fuel consumption valid for the entire flight sequence (but particularly for the "flight" engines considered).

Knowledge of the consumption of both jet engines provides the overall net thrust.

*The internal method:

Measurement of: dynamic pressure, temperature and total pressure for each nozzle allows the establishment of the output of each of the two flows, taking into account a coefficient of standard flow found in the databank. By means of a nozzle coefficient, determined from the databank, it is possible to calculate the gross thrust and then to get back to the net thrust.

It should be mentioned that for dynamic pressure, which is difficult to measure, it is possible to substitute the Mach number calculated for the start of the rate of expansion.

Finally, monitoring of the results can be obtained by using different powers, by calculation of the total flow at the level of the low pressure compressor or of the primary flow at the intake level of the high pressure turbine.

(2) Elaboration of aerodynamic stresses applied to the wings (ref. 14).

The details about overall effects of aerodynamic loads are obtained by investigating the general loads in the different sections (shear stress, bending moment and moment of torsion). Starting with determination of those data it will then be possible to return to the distribution of lift over the wingspan.

For that purpose each section under consideration is equipped with several straingauge bridges delivering signals (millivolts).

It is possible to go back to the F loads knowing the signals S, if one knows the matrix relation.

$$F = BS$$

It is determined on the ground by making a number of important calibrations that provide a signal matrix E. The liaison matrix is then generally determined by means of the least squares method:

$$B = FE^T(E\ E^T)^{-1}$$

To account for the distribution of aerodynamic stresses, at the wingspan and at the chord, the calibration forces are arranged so as to give the best representation of a theoretical shear force and expected moments of flexure and torsion. That determines a matrix of equilibrium P and provides the solution:

$$B = F\ (EP)^T\ ((EP)(EP)^T)^{-1}$$

The stresses investigated for one section being the integral of stresses between the tip and the section under consideration,and with the pickups being sensitive to the applied stresses between the section and the wing root, it is necessary to make corrections in accord with the signal produced by theoretical loads situated between the tip and the section under consideration, and the signal produced by the total wing load.

It still remains to correct the weight and inertial loads.

(3) Elaboration on the angle of attack and on the sideslip.

Calibration of the sensor for the angle of attack is carried out according to several methods.

*Comparison of individual points

The angle of attack is determined by establishment, or comparison with, of parameters of acceleration and of anemometry, recorded during stable flight or during boundary conditions of operations; a comparison can be made by derivation of the total anemometric pressure head, or better yet, by integrating the accelerations.

The calibration is found through application of several stabilizations at various angles of attack.

*Determination of the local pitch $k_\alpha = \Delta\alpha$ sensor/$\Delta\alpha$ for the airplane in the course of operation.

The integration of equation $\frac{d\alpha}{dt} = (\frac{d\alpha}{dt})^o + q - \beta p - \frac{g}{v}(nz - \cos\phi)$ gives the angle of attack of the airplane which, when compared to that picked up in flight, permits the determination of k.

The combination of the two methods leads to complete knowledge about the relation between the "airplane angle" and the "sensor angle" for the entire range of flight.

The values determined are corrected, with errors due to the sensor location or, in particular, to pitching and rolling speeds and to the flexure of the fuselage. The second method employed, starting /19-7 with the equation for lateral force, permits the calibration of the slide slip sensor.

(4) Corrections are:
- --for accelerometer positions
- --for the influence of thrust
- --for the influence the dynamic of the motion has on the parameters of steady flight
- --etc. . . .

(c) Methods for determining parameters

The processing of parameters recorded in flight has been standardized for computer handling and is carried out:

--in real time for a first approximation and a survey of important parameters

--in delayed time for complete processing.

The principal methods used are given here with their indicative titles:

(1) The method of least squares for handling of n equations with p unknowns ($p<n$). The coefficients obtained from the solution are found valuable in cases where relations between recordings in flight and coefficients are linear, as in:
Tracking stress = $k_1\beta + k_2\delta n + k_3\, p + k_4\, r$ (Fig. 6)

In the case where differential equations are used this method is highly disappointing.

(2) Method of dynamic optimization

Calculation is first made with estimated coefficients and later compared with flight data after investigation of influential coefficients, modified in the sense of reducing the gap between flight and simulation of it, with or without investigation of the influence of noise levels during measurement and processing. These comparisons can lead to extremely diverse parameters: Total altitude, climbing period, angular velocities, attitudes (Figs. 7, 8 and 9).

4. Results of the Comparison

The figures 10 to 40 present the results of various comparisons made for:

--the longitudinal coefficients

--the lateral coefficients at high speed, then at low speed and large angle of attack

--efficiency of the control surfaces

as well as their various factors obtained from windtunnel tests.

--hinge moments, wing stresses, types of side slipping, buffeting boundaries, spins.

(a) Longitudinal coefficients

Although there is good correlation between the theoretical calculation, windtunnel data and flight data, certain differences are apparent.

*In the static stability (Figs. 12, 15 and 16)

The calculation (DATCOM) is too optimistic while windtunnel results are close to those in flight. During these comparisons the engine influence was kept in mind, with the interaction of "Jet-horizontal stabilizer" modifying the zero lift moment. The influence of the jet could not be established in the windtunnel with any accuracy, due mainly to the difficulty of jet simulation.

*In the drag resistance (Fig. 13)

Windtunnel data and theoretical calculations give drag data superior to those taken in flight.

*In damping of pitching motion (Fig. 14)

Theoretically calculated damping is quite different from what is found in flight. That is due to overestimation of the efficiency of the control surfaces. On the other hand a rerun in the low speed windtunnel leads to an excellent approximation.

(b) Lateral coefficients

Certain lateral coefficients are not easily obtained during in-flight experiments. That is the case for interconnected coefficients, for instance: rolling due to yaw, or yaw due to rolling. In spite of it the correlation generally found is a good one. Some remarks are called for, about certain coefficients.

*Course stability (Figs. 22 and 28)

The calculation leads to a course stability that is far removed from that found during flight or in windtunnel tests, the difference being due in particular to an underestimate of the vertical stabilizer efficiency. The difficulty of obtaining $C_{n\beta}$ also appears in windtunnel tests, when looking at the results for low and medium speed (Fig. 28). Flight data are somewhere between the results of the windtunnels of Amsterdam and those of Göttingen.

*Rolling due to slideslipping (Figs. 21 and 27)

The differences observed, between the results of calculations and of windtunnel tests, can be explained by a poor determination of the dihedral influence. Those differences are attenuated as we compare flight and windtunnel data. As in the case of the $C_{n\beta}$, the difference between the estimates and the windtunnel velocity should be noted (Fig. 27). The influence of the flaps is less important in flight than in the estimates.

(c) Efficiency of the control surfaces

The correlation between the windtunnel results and those obtained from flight tests is correct. It is worth mentioning the difficulties encountered in investigating the aileron efficiency, which is slightly nonlinear with steering. This nonlinearity becomes important for large Mach numbers and outside the flight domain of the airplane. The windtunnel tests for such high Mach numbers do not indicate such a tendency.

The theoretical calculation generally shows efficiencies that are too high.

(d) Stresses (Reference 15) /19-8

While the hinge moments have generally been well determined in the windtunnel, it must be mentioned that there were problems in obtaining wing stresses. Fig. 38 presents the results of theoretical three-dimensional calculations with and without flow separation at the stabilizer contours of the tips. It shows that a good representation of the physical system accounts for excellent accuracy in the calculation of the pressure distribution.

(e) Buffeting (Fig. 16)

The buffeting model offers similarity in weight and rigidity to the airplane for the Mach number and altitude of a chosen data point. An error of 15% in the buffeting velocity is included for the model at that point. For other points in the flight domain the error varies as a function of the pressure (regulated) and the temperature (induced) of the windtunnel. Fig. 39 represents the development of a type of pitching due to outside stress, as a function of the generating pressure. The comparison (considering the variable errors and the similarity factors) with results from flight tests is very good.

(f) Spins (qualitative comparisons)

The windtunnel, which does not permit the study of normal flight transition and stalled flight, permitted the demonstration of three types of spin (vertical, slightly inclined and horizontal) that can degenerate into transverse diverging shaking, continuous rotations,or classic outputs. That classification was also found during flight tests, both as far as the basic aspect of these phenomena is concerned and for the parameters of attitude and turn period. The same is true in the case of the control surfaces (the important role of aileron deflection being in agreement with the deflections of the elevator and the rudder has been foreseen) where windtunnel tests lead to correct, though simplified, output procedures when the spin is not horizontal.

The only parameter not studied in the windtunnel is the influence of altitude in flight as important factor playing a role in the generation of spins.

(g) Air intake (Fig. 10)

The figure compares the maps showing the air intake at the windtunnel and in flight, showing very good agreement between the results.

5. Conclusion

Following this comparison, which is quantitatively limited to the nonstall domain, it appears that the estimated aerodynamic coefficients, the result of judicious association of windtunnel tests with theroretical calculations, have attained a high degree of probability for the Alpha-Jet. This is due to:

- --the number of important tests carried out with models and in windtunnels of great variety.
- --to the accuracy of the results obtained with modern methods of calculation and in particular with three-dimensional aerodynamics and aeroelasticity calculations using the finite element method.

In addition, for this particular airplane, comparison with actual flight conditions was facilitated through a great number of tests in flight whose utilization was simplified by the good linearity of the majority of coefficients and by the closeness of the estimated data bases.

It is now possible, to any extent, to give an answer to the question of how high the degree of credibility is that can be attached to results estimated on the basis of theoretical calculations and windtunnel tests?

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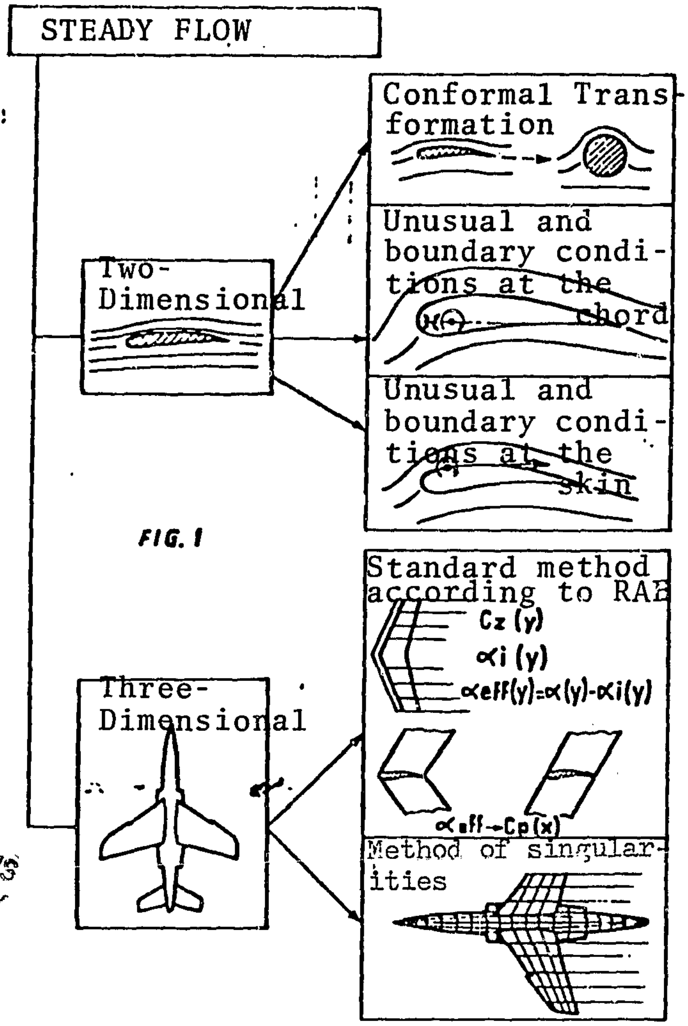


FIG. 1

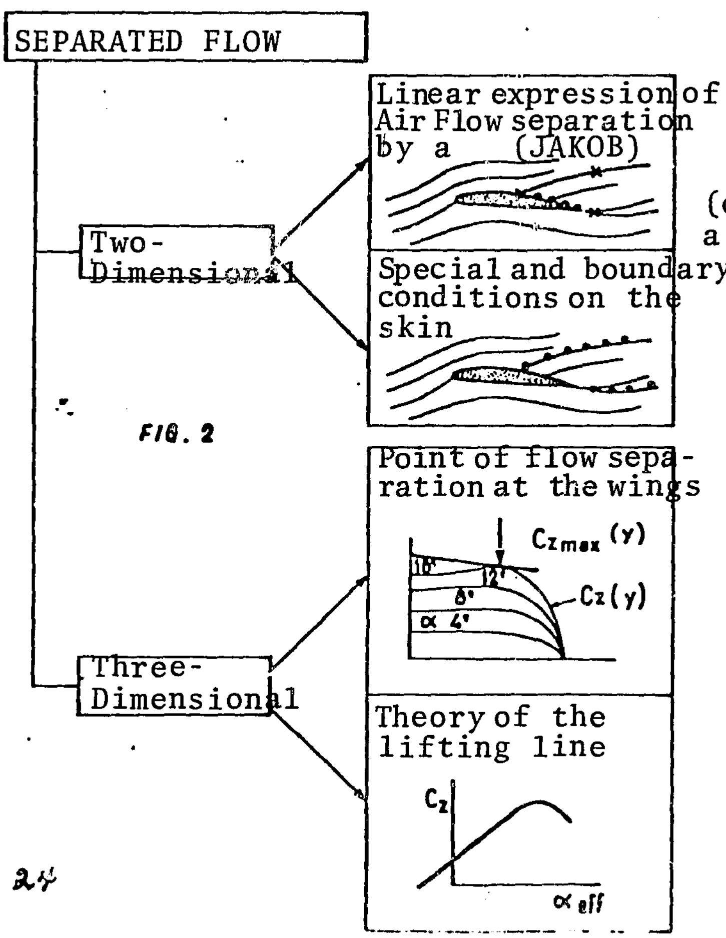


FIG. 2

FIG. 3 - Validity Boundaries for Different Methods of Theoretical Calculation

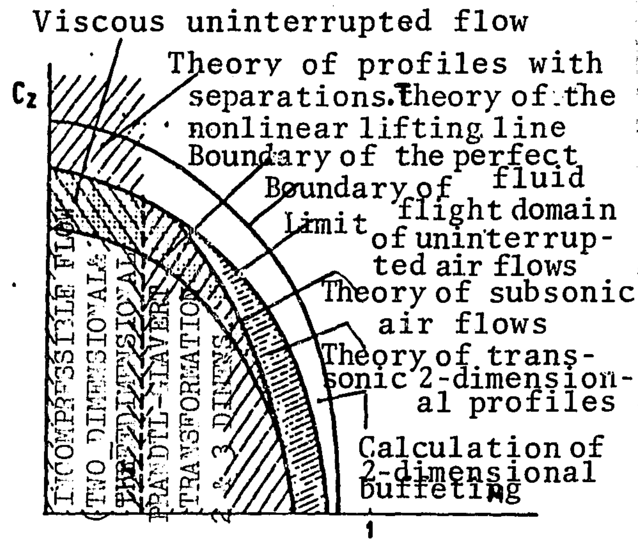


FIG. 4 - Example of Interactions with the Windtunnel Walls

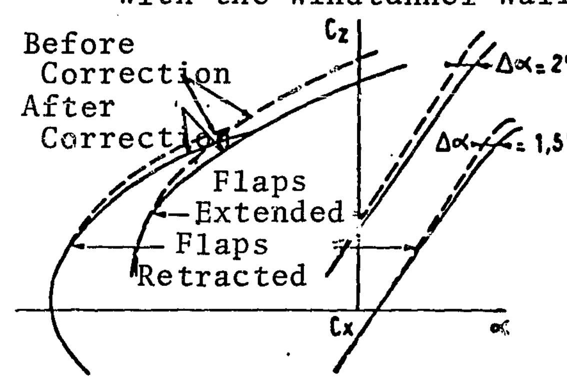


FIG. 5 - Lift Distribution Due to Aileron Deflection (comparison between a rigid and a flexible airfoil)

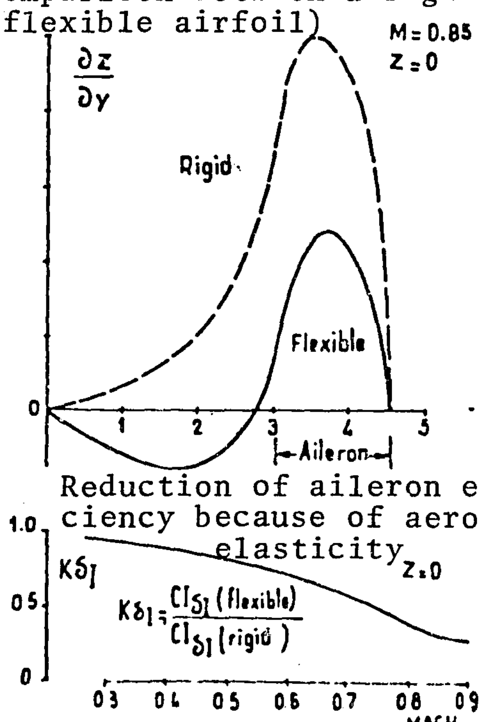


FIG.6 - Example of Reconstitution of the Hinge Movement

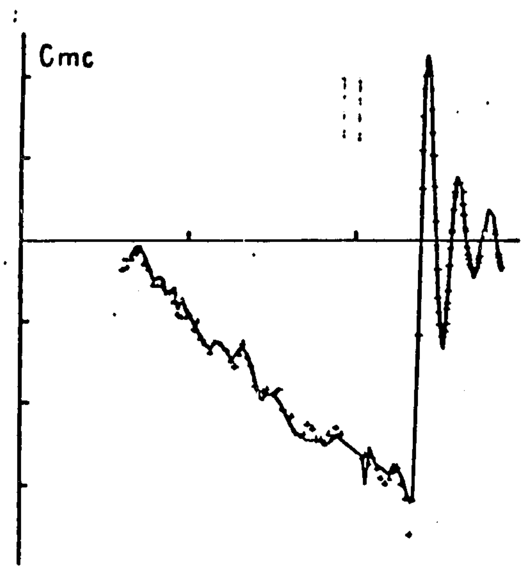


FIG.7 - Example of Reconstitution of Elevator Stress (Method 2)

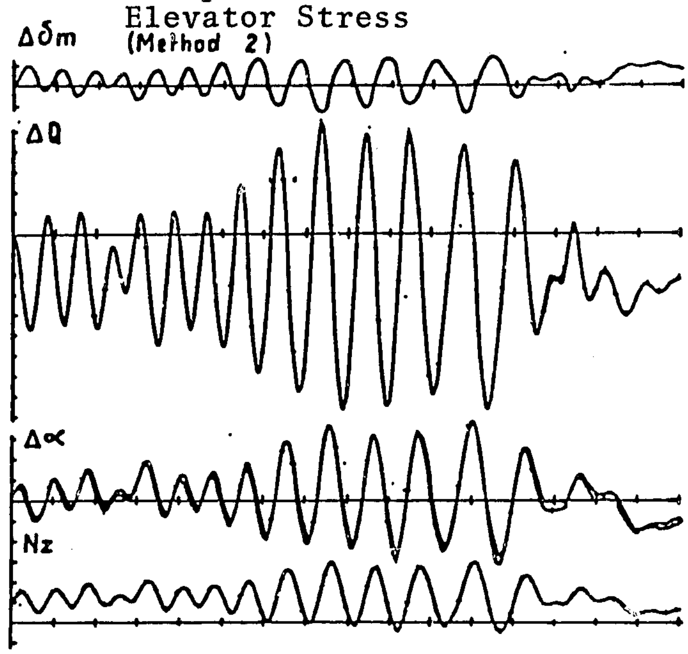


FIG.8 - Example of Reconstitution of Rudder Stress (Method 2)

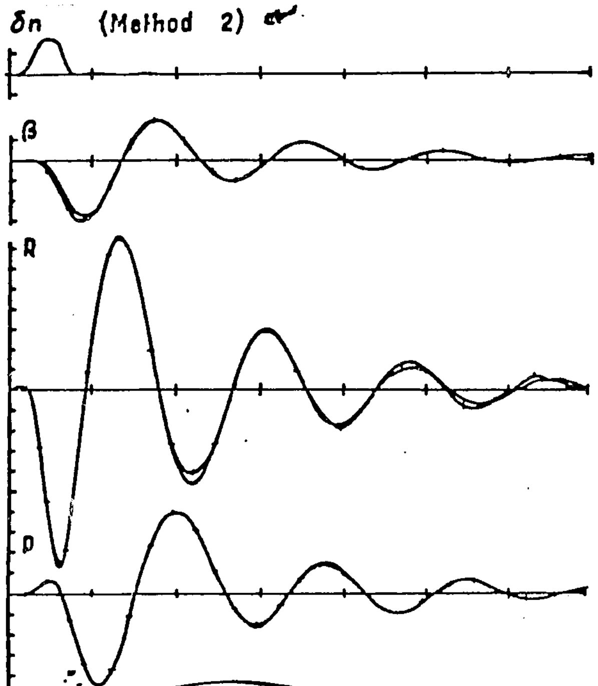


FIG.9 - Example of Reconstitution Horizontal Spin (Method 2)

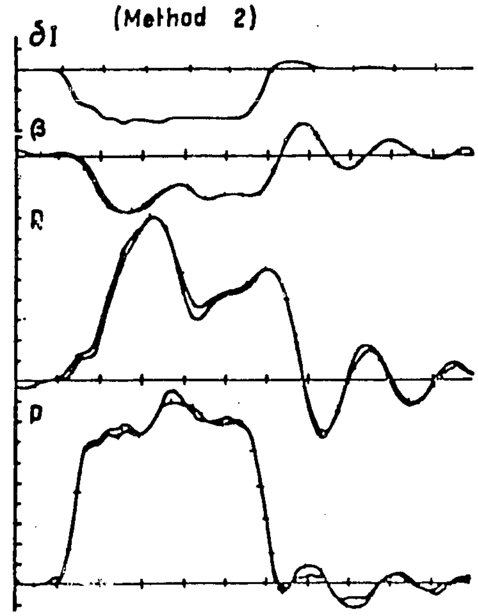
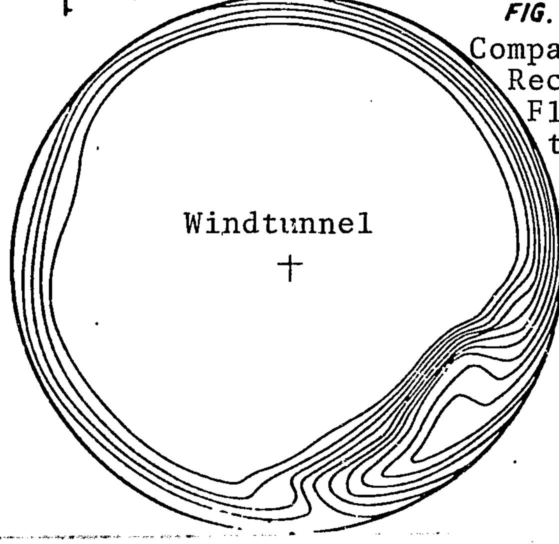


FIG.10 - 'Air Intake Comparison Between Records Made in Flight and in the Windtunnel
$\alpha = 14°5$



Shown at low velocity maximum power

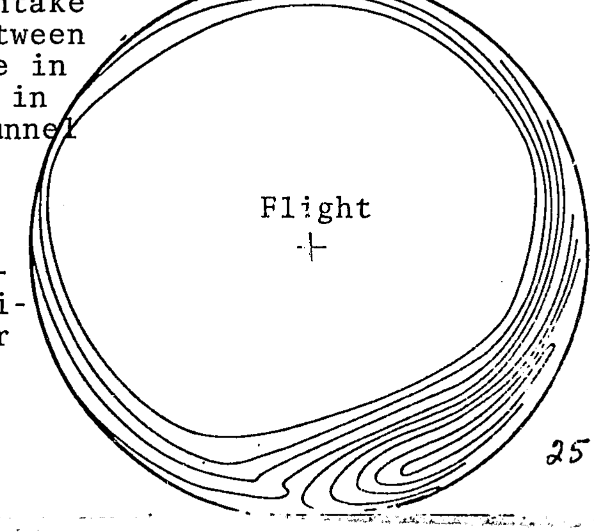


FIG. 11
Lift

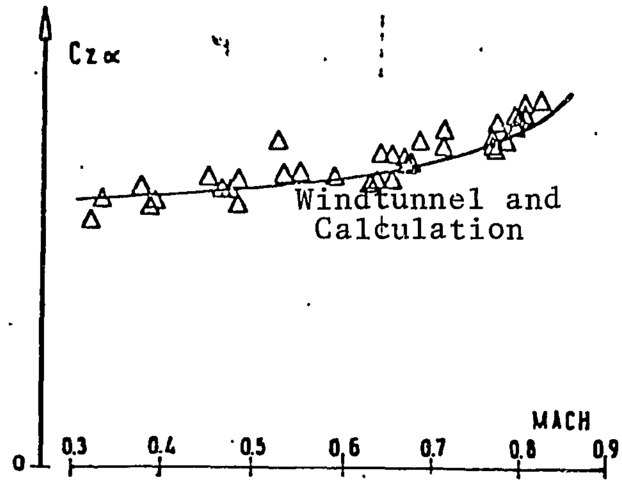


FIG. 12
Static Stability

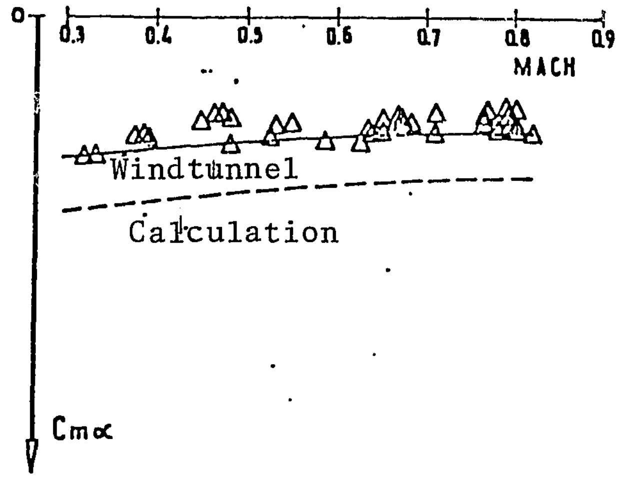


FIG. 13
Drag Resistance

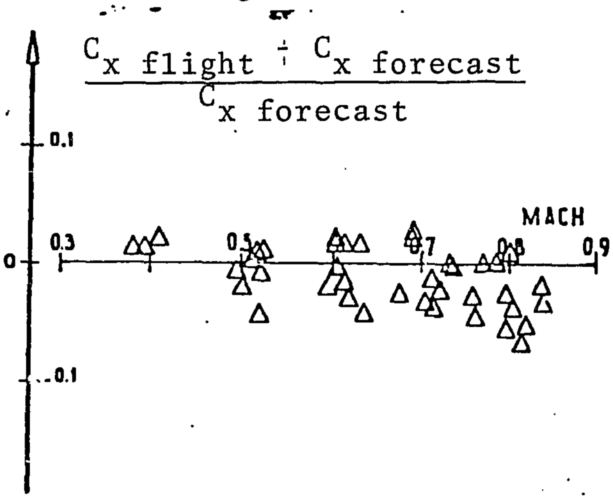


FIG. 14
Pitch Damping

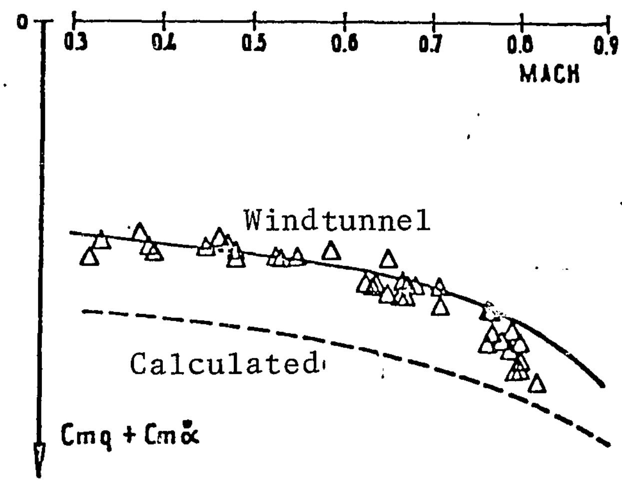


FIG. 15
Static Longitudinal Stability

M: 0.8

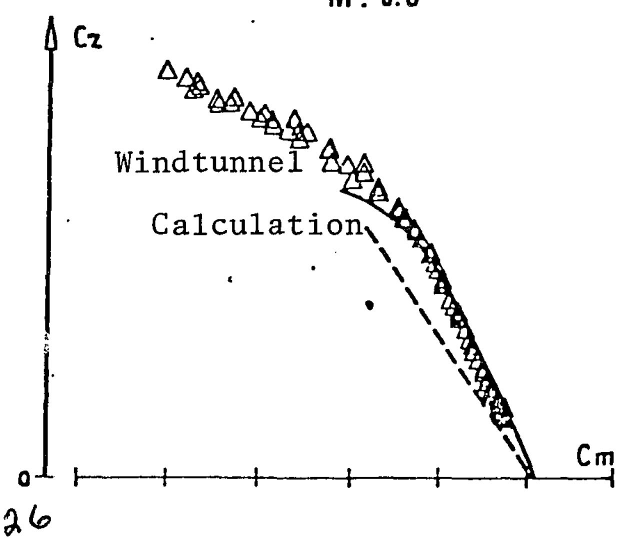


FIG. 16
Static Longitudinal Stability

M: 0.4

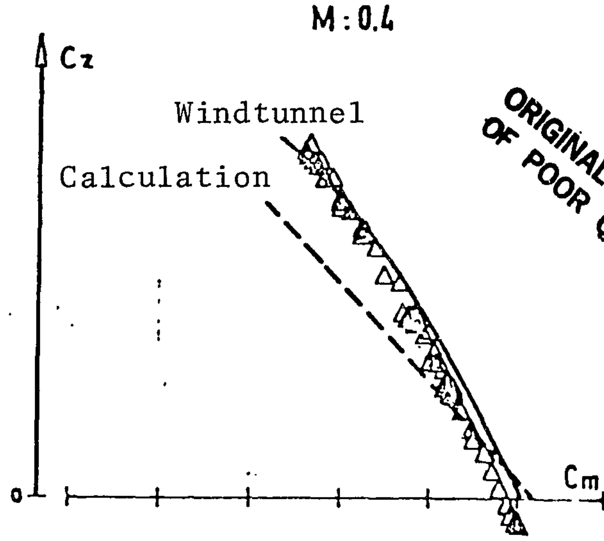


FIG. 17
Roll Damping

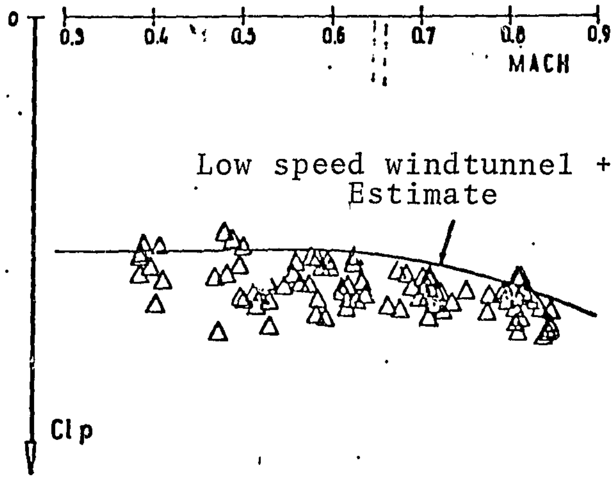


FIG. 18
Yaw Due to Roll

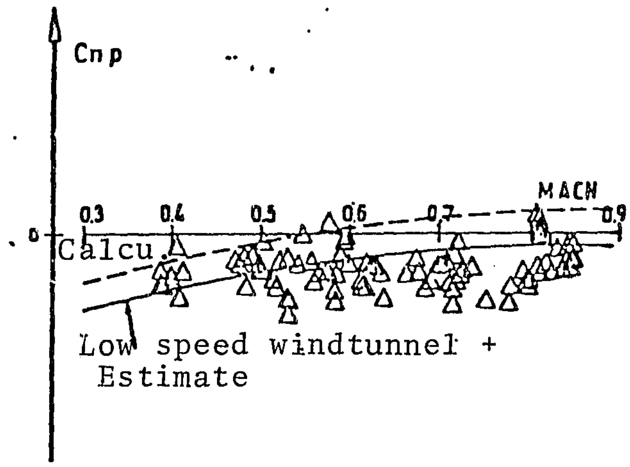


FIG. 19
Roll Due to Yaw

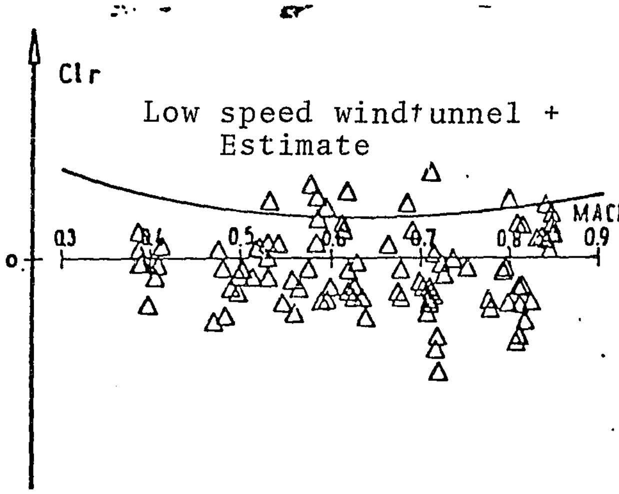


FIG. 20
Yaw Damping

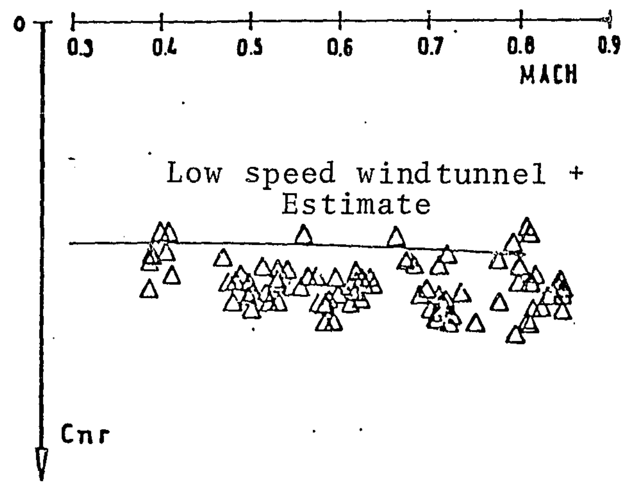


FIG. 21
Roll Due to Side Slip

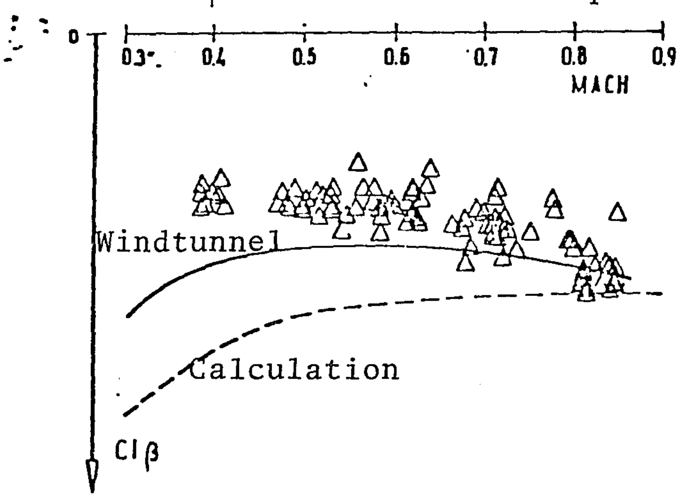


FIG. 22
Course Stability

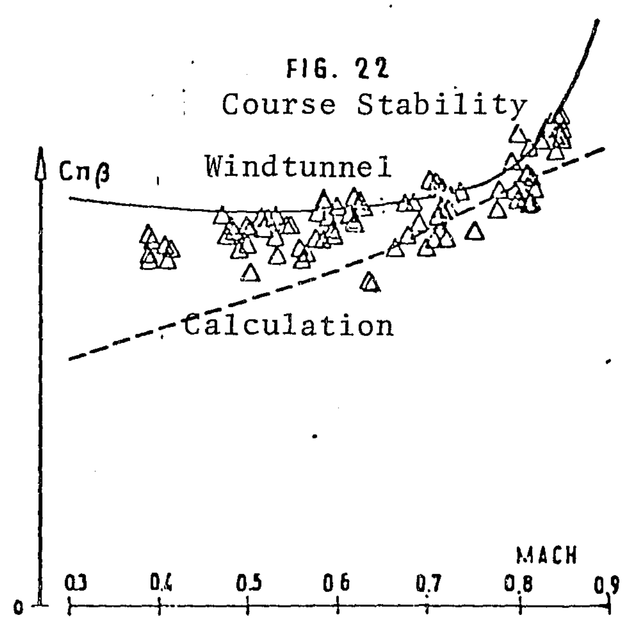


FIG. 23
Roll Damping

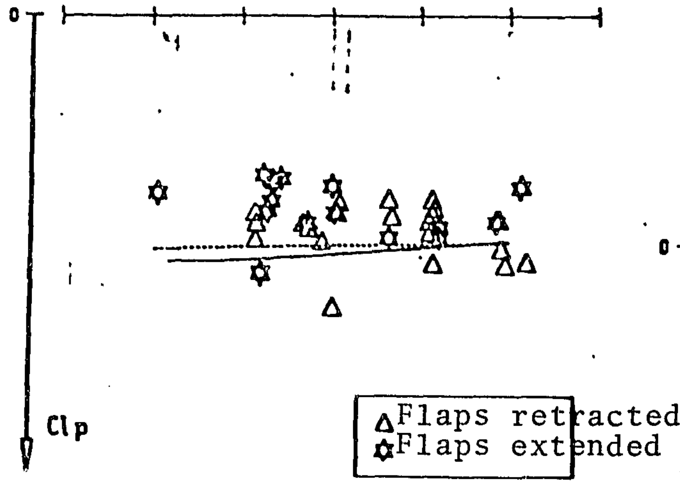


FIG. 24
Yaw Due to Roll

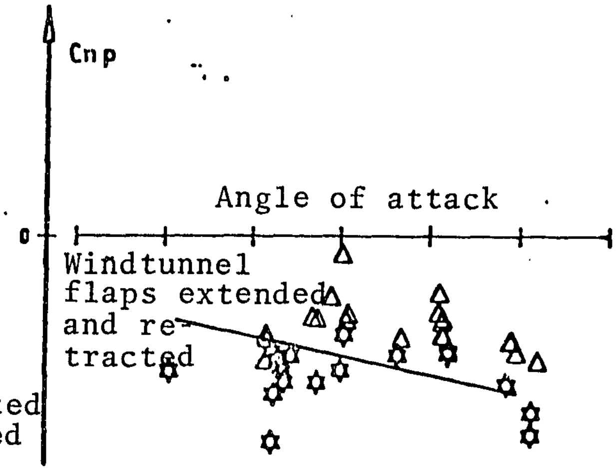


FIG. 25
Roll Due to Yaw

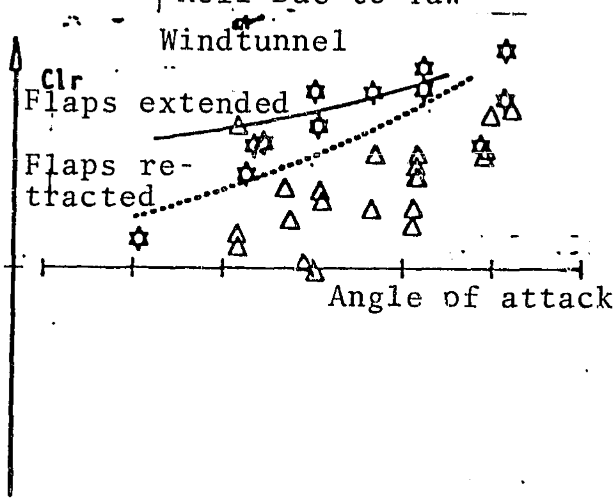


FIG. 26
Damping of Yaw

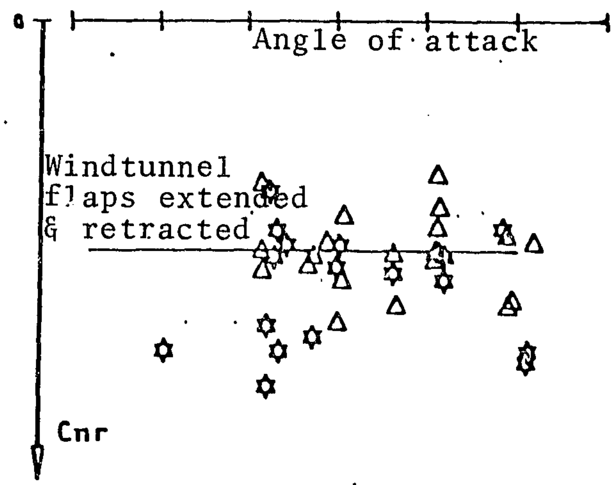


FIG. 27
Roll Due to Side Slip

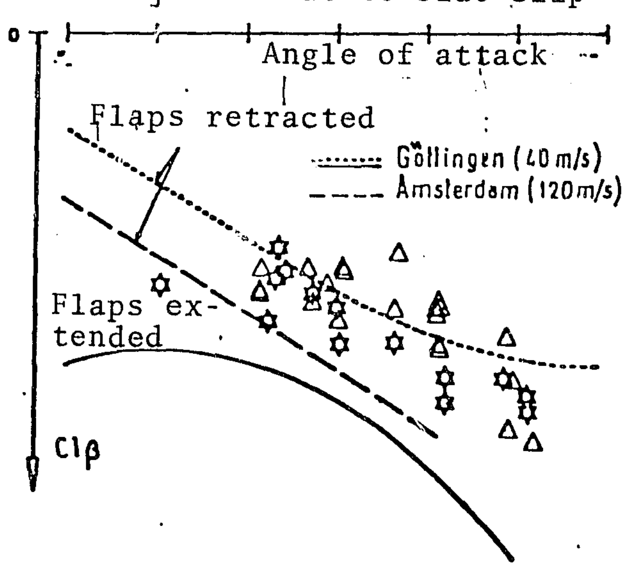


FIG. 28
Course Stability

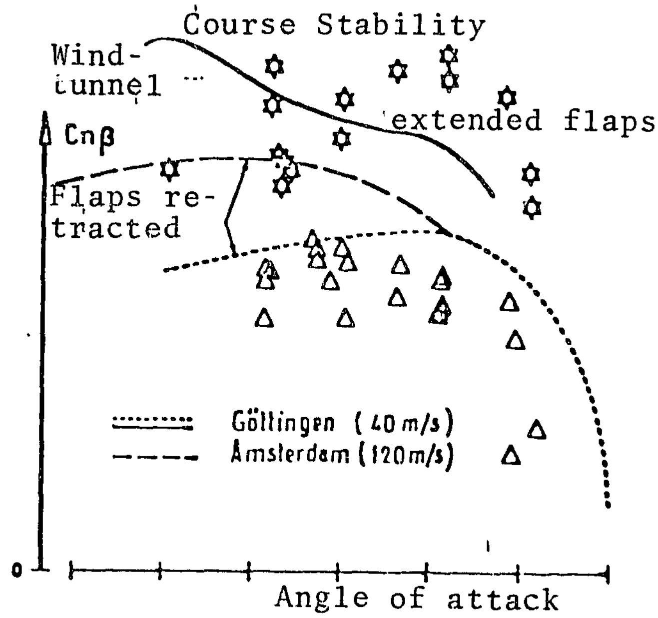


FIG. 29

Aileron Efficiency

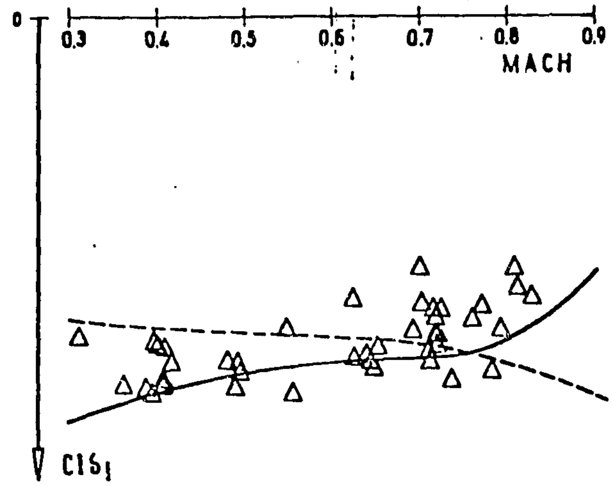


FIG. 30

Yaw Due to Ailerons

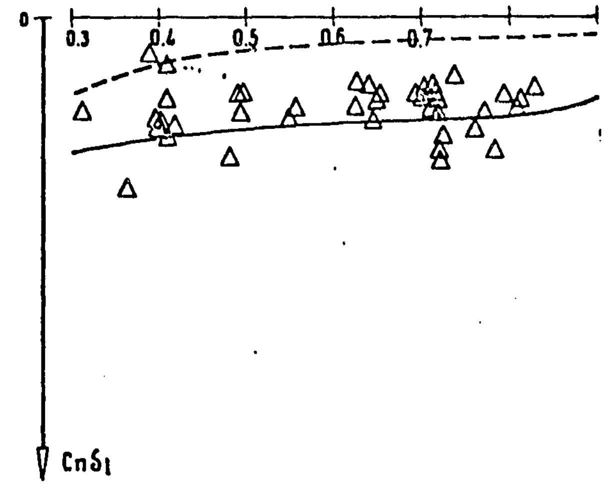


FIG. 31

Roll Due to Rudder

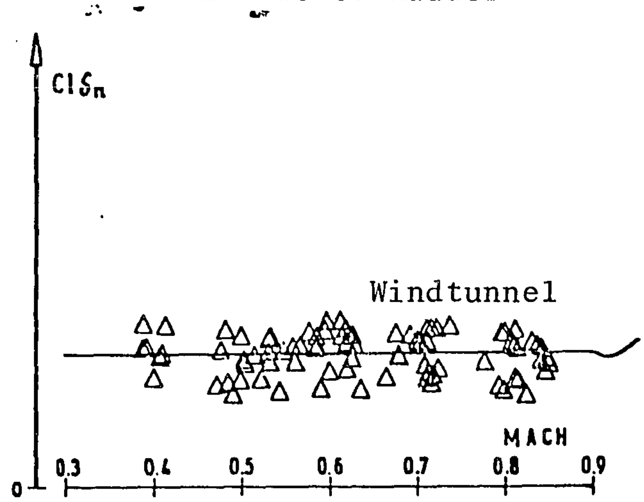


FIG. 32

Rudder Efficiency

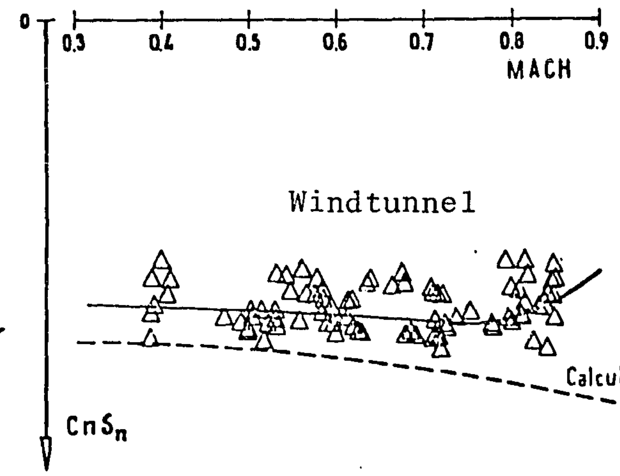


FIG. 33

Elevator Efficiency

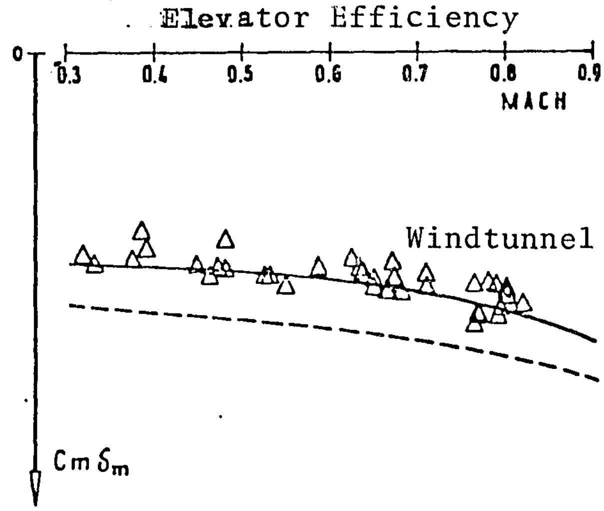


FIG. 34

Calibration of Side Slip Sensor

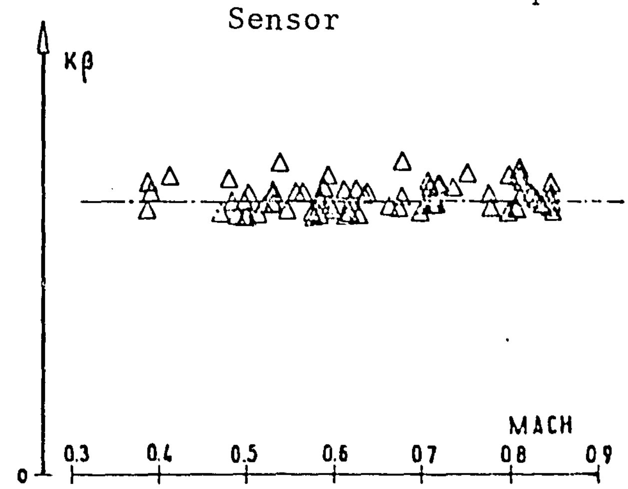


FIG. 35
Calibration of Angle of Attack
Dynamic Method

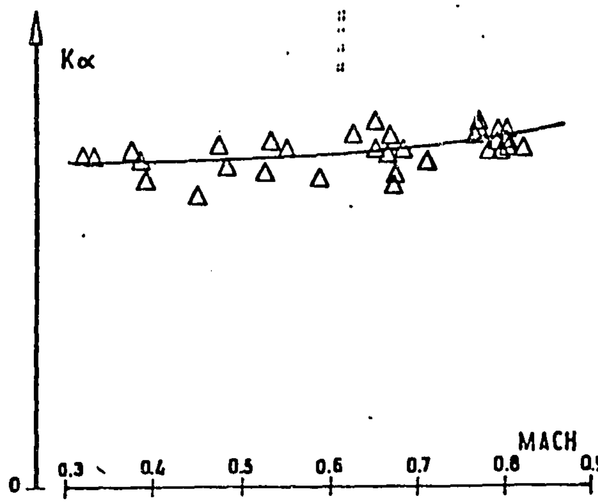


FIG. 36
Calibration of Angle of Attack
Static Method

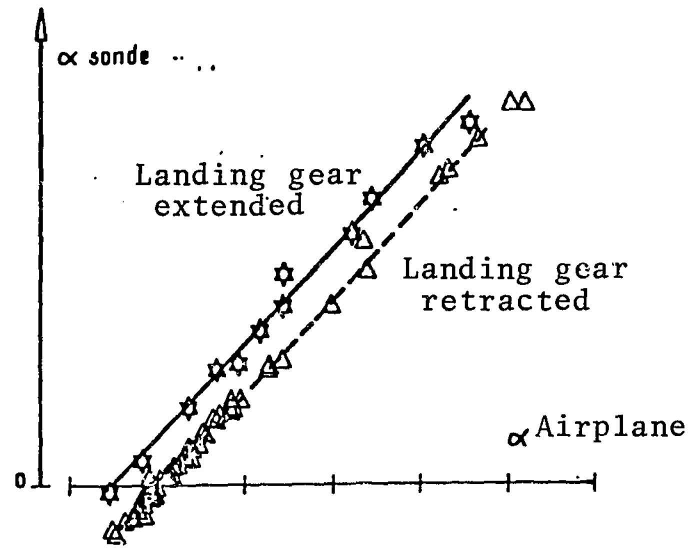


FIG. 37
Structural Loading
Asymmetric Couple
at the Tail Unit

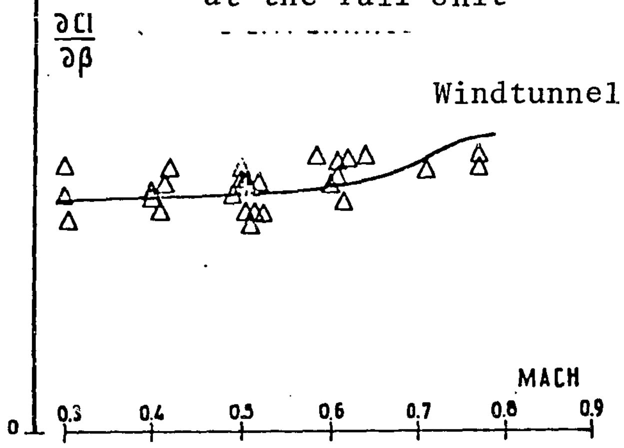


FIG. 38
Structural Loading
Movement of Wing Flexure

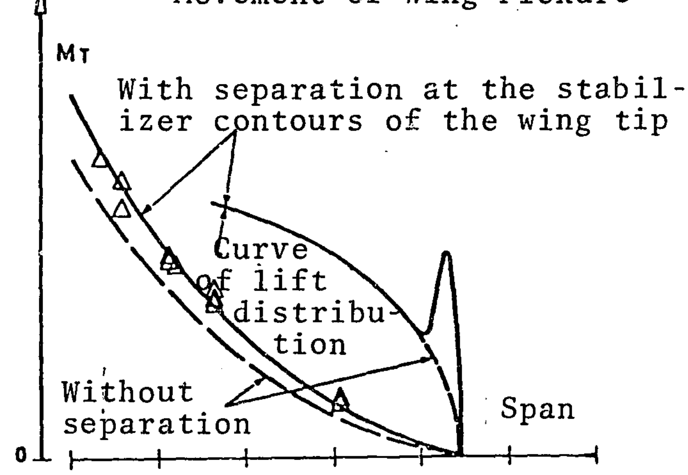


FIG. 39
Buffeting
Development of a Critical
Method

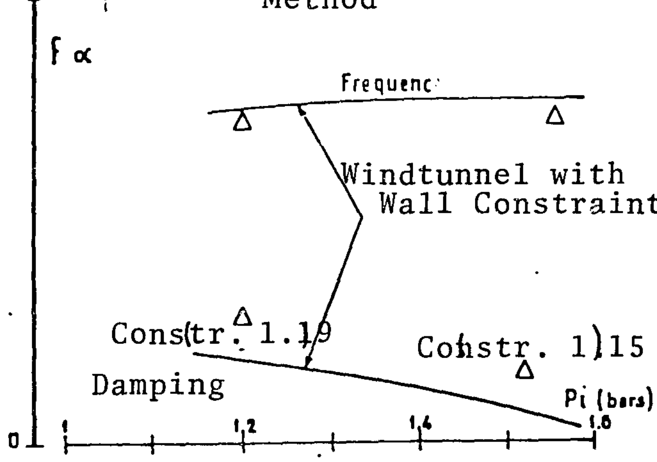


FIG. 40
Boundaries of Buffeting
and of Application